Propagation and Scattering in a Variable Shallow Water Waveguide

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LONG-TERM GOALS

The long-term goal is to develop models for mid-frequency (1-10 kHz) acoustic propagation and scattering effects that can form the basis for model-based signal processing algorithms. Specifically, this includes deterministic propagation effects as encompassed in the so-called waveguide invariant and random scattering effects as represented by the scintillation index.

OBJECTIVES

The primary objective in FY11 was to develop a method of broadband stiration-based beamforming that would allow one to estimate the numerical value of the waveguide invariant. Secondary efforts in collaboration with other investigators involved blind channel estimation and characterizing the acoustic scinitillation observed in an existing data set.

APPROACH

The approach is a mixture of data analysis, numerical simulations, and analytical modeling. Existing data sets collected under ONR support are exploited in novel ways; the present work uses data collected during the 2001 ASIAEX experiment, the Shallow Water 2006 (SW06) experiment and the 2009 Cooperative Array Performance Experiment (CAPEx09). Numerical simulations were performed using existing parabolic equation, normal mode, and ray trace computer routines developed by many different investigators under ONR support. In FY11 the analytical modeling emphasized using a perturbation approach to extend single-frequency normal mode calculations to a broader frequency band so they could then be used in a broadband beamformer.

The work on broadband beamforming using the waveguide invariant was done in collaboration with Dr. Lisa Zurk (Portland State University). Environmental data collected during ASIAEX were used to simulate the output of the beamformer. The CAPEx09 data were used with Dr. David Dowling (University of Michigan) to do channel estimation and blind deconvolution. Acoustic scintillation was investigated with Dr. Dajun Tang (APL-UW) using SW06 data.

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WORK COMPLETED

The work completed in FY11 was documented in one journal paper that was submitted and published, a second journal paper that was submitted, and an invited conference paper.

A striation-based beamforming method was developed that allows one to estimate the numerical value of the waveguide invariant independent of the range to the source. In conventional beamforming, one can estimate the ratio between the waveguide invariant and the range but cannot separate the two terms. Hence if the the final goal is to estimate the range to a source, one must first assume that the numerical value for the waveguide invariant is known by other means. A common choice in shallow water is to assume that the waveguide invariant $\beta = 1.0$. When there is a significant thermocline, however, both simulations and experimental data have shown that larger values of β are typical. The impact on range estimation with conventional processing is significant; for example, a 30 percent error in the assumed numerical value for β translates directly into a 30 percent error in the estimated range. With striation-based beamforming, one does not have to assume a priori a numerical value for β as the processing produces estimates for both range and the waveguide invariant. The completed analysis was published in the Journal of the Acoustical Society of America (JASA).

Work completed with Dr. Dowling on channel estimation has been submitted to JASA. Work completed with Dr. Tang on acoustic scintillation was documented in the conference paper.

RESULTS

Striation-based beamforming for estimating the waveguide invariant relies on twice beamforming the acoustic pressure measured on a horizontal array. The data are first beamformed conventionally at a single frequency. The beamformer output is a maximum at the true bearing of the source. The pressure is then beamformed again but this time with the frequency shifted so each element on the array is evaluated at a slightly different frequency. The beamformer maximum will shift away from the true bearing. The extent of the shift can be used to estimate the wavegude invariant.

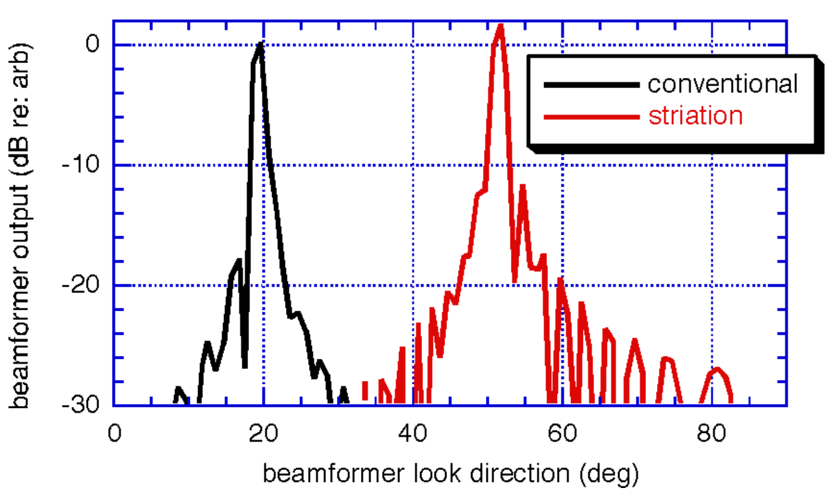

FIG. 1. Striation-based beamforming example. Beamformer output plotted versus look direction for both conventional and frequency-shifted processing.

Figure 1 shows a numerical example of striation-based beamforming. A mid-frequency scenario is simulated using environmental data collected during ASIAEX. With conventional beamforming, the beamformer focuses at the correct bearing of the source, ϕ_0=20 deg. When the frequency is shifted across the array, the focus shifts to ϕ=52 deg. The numerical value for the waveguide invariant is then determined by the formula

$$\sin(\phi) \approx \sin(\phi_0)(1+\beta)$$

to be β=1.3, a reasonable value when both the source and receiver are below a sharp thermocline.

As evidenced by the growing literature on the topic, the waveguide invariant concept is being applied in an ever growing number of sonar signal processing algorithms. The significance of the present result is that it developes an independent means for quantifying the numerical value of the invariant that should be used in these algorithms.

IMPACT/APPLICATIONS

The waveguide invariant is already used in applied sonar signal processing algorithms. The work completed under present support gives a new method for determining the numerical value of the waveguide invariant.

RELATED PROJECTS

The collaborators mentioned above have separate ONR funding for their work. Numerous other investigators continue to analyze the SW06 data set.

PUBLICATIONS

S. H. Abadi, D. Rouseff and D. R. Dowling, "Blind deconvolution for robust signal estimation and approximate source localization," *J. Acoust. Soc. Am*. (2011). [submitted, refereed]

D. Rouseff, D. Tang and F. S. Henyey, "Effect of Linear Internal Waves on Mid-Frequency Acoustic Fluctuations in Shallow Water," in *4th Proc. Underwater Acoustic Measurements*, Kos, Greece, 20-24 June, 2011. [invited, non-refereed]

D. Rouseff and L. M. Zurk, "Striation-based beamforming for estimating the waveguide invariant with passive sonar," *J. Acoust. Soc. Am*. 130 (2), EL76-EL81, (2011). [published, refereed]